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Bioefficacy of Lysine from L-lysine Sulfate and L-lysine·HCl for 10 to 20 kg Pigs

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ABSTRACT : The objective of this study was to compare the bioefficacy of L-lysine sulfate relative to L-lysine·HCl for 10 to 20 kg pigs. Two experiments were conducted to determine the bioefficacy of the two sources of lysine using daily gain, feed conversion, plasma urea nitrogen and nitrogen retention as the response criteria. In experiment 1, 168 crossbred barrows (Landrace×Large White), weaned at 28±3 d (9.07±0.78 kg body weight), were allotted to one of seven dietary treatments in a 2×3 (two lysine sources×three lysine levels) factorial arrangement of treatments with an added negative control treatment group. The basal diet was based on corn, peanut meal and soybean meal and provided 0.67% lysine. The basal diet was supplemented with 0.1, 0.2 or 0.3% lysine equivalents supplied from either L-lysine sulfate or L-lysine·HCl. Each treatment was fed to six pens of pigs with four pigs per pen. The trial lasted 21 days. The relative bioefficacy value of lysine in L-lysine sulfate using daily gain, feed conversion and plasma urea nitrogen as response criteria was 1.01, 1.05 and 1.04 of the lysine in L-lysine·HCl, respectively. In experiment 2, 42 crossbred (Landrace×Large White) pigs (16.03±1.58 kg body weight) were housed in stainless steel metabolism cages for 10 d and fed the seven diets used in the nitrogen-balance trial. The relative bioefficacy value of L-lysine sulfate was estimated to be 0.95 as effective as L-lysine·HCl for nitrogen retention on an equimolar basis. The t-test analysis revealed that bioefficacy of lysine in L-lysine sulfate was not significantly different from lysine in L-lysine·HCl, which was set at 1.00. In conclusion, L-lysine sulfate can be used instead of L-lysine ·HCl to fortify lysine-deficient diets fed to 10 to 20 kg pigs. (**Key Words** : Pigs, L-lysine Sulfate, L-lysine·HCl, Bioefficacy, Nitrogen Retention, Performance)

INTRODUCTION

Lysine is commonly the first-limiting amino acid in diets fed to pigs (Mavromichalis et al., 1998; Susenbeth et al., 1999; Chang and Wei, 2005), and it has become an established practice to supplement pig diets with crystalline lysine to meet the requirements of swine during the different phases of the growing period. Typically, L-lysine·HCl (78% lysine) is the traditional source of additional lysine used in animal feeds (Jackson, 2001).

Recently, an alternative source of lysine in the form of L-lysine sulfate (50% lysine) has been developed. Both L-lysine sulfate and L-lysine·HCl, are produced by bacterial fermentation of carbohydrates, but the post-fermentation process for L-lysine sulfate differs from that of L-lysine·HCl (Rodehutscord et al., 2000) with its production being highly attractive for both ecological and economical reasons (Kircher and Pfefferle, 2001). This new source is a dry, granular product composed of L-lysine sulfate and fermentation by-products containing other amino acids, phosphorus and energy. These fermentation by-products are not present in L-lysine·HCl product (Jackson, 2001).

A recent study conducted by Smiricky-Tjardes et al. (2004) reported that the bioefficacy of L-lysine sulfate relative to L-lysine·HCl was similar when using daily gain and feed conversion of young pigs as the response criteria. In addition, several other swine and broiler experiments had been conducted to compare the bioefficacy of lysine in L-lysine sulfate and L-lysine·HCl (Rostagno, 1999; Emmert and Pope, 2000; Neme et al., 2001). Most of these studies used animal performance as the main response variable. However, very little research has been conducted to determine the bioefficacy of lysine sources using nitrogen retention or plasma urea nitrogen as the response variable. Therefore, the present study was conducted to examine the

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Table 1. Ingredient and chemical composition (% diet) of the experimental diets (as fed) in experiment 1

Item	Basal	L-lysine sulfate			L-lysine·HCl		
Lysine equivalent level	0.0	0.1	0.2	0.3	0.1	0.2	0.3
Ingredient							
Corn	55.53	55.33	55.13	54.93	55.40	55.27	55.14
Peanut meal	29.30	29.30	29.30	29.30	29.30	29.30	29.30
Soybean meal	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Dried whey	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Dicalcium phosphate	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Limestone	1.17	1.17	1.17	1.17	1.17	1.17	1.17
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Soybean oil	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Minerals and vitamins[1]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Choline chloride[2]	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DL-methionine	0.02	0.02	0.02	0.02	0.02	0.02	0.02
L-threonine	0.09	0.09	0.09	0.09	0.09	0.09	0.09
L-lysine sulfate	-	0.20	0.40	0.60	-	-	-
L-lysine·HCl	-	-	-	-	0.13	0.26	0.39
Analysed chemical composition[3]							
Dry matter	89.37	89.21	89.51	89.29	89.41	89.65	89.23
Ash	6.40	6.36	6.42	6.41	6.40	6.39	6.42
Crude protein	21.70	21.90	21.80	22.00	21.80	21.70	21.60
Crude fiber	1.99	1.92	1.87	1.97	1.95	1.94	1.98
Lysine	0.67	0.77	0.85	0.95	0.78	0.87	0.98
Threonine	0.66	0.66	0.65	0.65	0.66	0.64	0.63
Methionine	0.31	0.30	0.28	0.29	0.30	0.30	0.29
Methionine+cystine	0.61	0.61	0.63	0.60	0.62	0.60	0.59
Tryptophan	0.22	0.22	0.20	0.21	0.23	0.21	0.20

[1] Provided per kilogram of diet: vitamin A, 11.0 mg; vitamin D_3, 4.4 mg; vitamin E, 60.0 mg; vitamin B_{12}, 27.6 μg; riboflavin, 5.5 mg; thiamine, 2 mg; D-pantothenic acid,13.8 mg; niacin, 30.3 mg; pyridoxine, 6 mg; Fe, 100 mg; Ze, 100 mg; Cu, 120 mg; I, 0.4 mg; Se, 0.3 mg; Co, 1.0 mg.

[2] Choline chloride is separately supplemented and it's concentration is 50%.

[3] Metabolizable energy in the basal diet was calculated to be 3,273 kcal/kg.

bioefficacy of L-lysine sulfate compared with L-lysine·HCl in young barrows using growth performance, plasma urea nitrogen and nitrogen balance as response variables.

MATERIALS AND METHODS

The animal protocols used in these experiments were approved by the Animal Care and Use Committee of China Agricultural University. The L-lysine sulfate and L-lysine·HCl were manufactured by Changchun Dacheng Biochemical Engineering Development Co., Ltd. (Changchun, China), using microbial fermentation process.

Experiment 1

Experiment 1 was conducted in the Ninghe Breeding Pig Farm located in Tianjin, China. A total of 168 crossbred (Landrace×Large White) barrows, weighing 9.07±0.78 kg, were allotted to seven treatments with six replicates in each on the basis of weight and litter of origin in a 2×3 factorial arrangement of treatments with an added negative control treatment group experiment involving two lysine sources (L-lysine sulfate vs. L-lysine·HCl) and three lysine equivalent addition levels (0.1, 0.2 and 0.3%). The basal diet contained 0.67% lysine (Table 1). The other six experimental diets consisted of the basal diet supplemented with either L-lysine sulfate containing 50% lysine (0.2, 0.4 and 0.6%) or L-lysine·HCl containing 78% lysine (0.13, 0.26 and 0.39%) on an equimolar basis.

The experimental diets were formulated following an analysis of all main ingredients for amino acid and crude protein content. The experimental diets were based on corn, peanut meal and soybean meal. Peanut meal was chosen as one of the main protein sources because it supplied a good balance of all essential amino acids with the exception of lysine. The experimental diets met requirement estimates for all nutrients except lysine (NRC, 1998).

All pigs were housed in an enclosed building with the temperature and humidity automatically monitored through an environmental control system. The temperature ranged from 23 to 27°C and humidity from 45 to 65%. Ammonia and carbon dioxide levels were kept below recommended levels for the duration of experiment.

The pigs were housed, four to a pen, in 1.20 m×1.20 m pens equipped with nipple drinkers and plastic slotted floors. Feed was provided in mash form and on an *ad libitum* basis through the whole experiment. Pigs were also provided with

Table 2. Ingredient and chemical composition (% diet) of the experimental diets (as fed) in experiment 2

Item	Basal	L-lysine sulfate			L-lysine·HCl		
Lysine equivalent level	0.0	0.1	0.2	0.3	0.1	0.2	0.3
Ingredient							
Corn	53.10	52.90	52.70	52.50	52.97	52.84	52.71
Peanut meal	32.60	32.60	32.60	32.60	32.60	32.60	32.60
Soybean meal	3.60	3.60	3.60	3.60	3.60	3.60	3.60
Dried whey	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Dicalcium phosphate	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Limestone	1.17	1.17	1.17	1.17	1.17	1.17	1.17
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Soybean oil	2.55	2.55	2.55	2.55	2.55	2.55	2.55
Minerals and vitamins[1]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Choline chloride[2]	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DL-methionine	0.02	0.02	0.02	0.02	0.02	0.02	0.02
L-threonine	0.07	0.07	0.07	0.07	0.07	0.07	0.07
L-lysine sulfate	-	0.20	0.40	0.60	-	-	-
L-lysine·HCl	-	-	-	-	0.13	0.26	0.39
Analysed chemical composition[3]							
Dry matter	91.15	90.62	90.75	90.85	90.66	90.87	91.36
Ash	5.85	5.82	5.87	5.83	5.79	5.82	5.84
Crude protein	21.50	21.60	21.90	21.90	21.80	21.70	22.30
Crude fiber	2.36	2.43	2.32	2.35	2.39	2.37	2.33
Lysine	0.66	0.74	0.86	0.92	0.78	0.84	0.95
Threonine	0.64	0.63	0.64	0.62	0.65	0.62	0.64
Methionine	0.31	0.31	0.32	0.30	0.33	0.30	0.32
Methionine+cystine	0.60	0.59	0.61	0.57	0.62	0.58	0.62
Tryptophan	0.21	0.20	0.21	0.18	0.22	0.19	0.20

[1] Provided per kilogram of diet: vitamin A, 11.0 mg; vitamin D_3, 4.4 mg; vitamin E, 60.0 mg; vitamin B_{12}, 27.6 μg; riboflavin, 5.5 mg; thiamine, 2 mg; D-pantothenic acid,13.8 mg; niacin, 30.3 mg; pyridoxine, 6 mg; Fe, 100 mg; Ze, 100 mg; Cu, 120 mg; I, 0.4 mg; Se, 0.3 mg; Co, 1.0 mg.

[2] Choline chloride is separately supplemented and it's concentration is 50%.

[3] Metabolizable energy in the basal diet was calculated to be 3,265 kcal/kg.

ad libitum access to water.

Pigs and feed were weighed at the start and end of the experiment to determine daily gain, feed intake and feed conversion for the 21-day experimental period. On day 21, approximately 7 ml of blood was collected by jugular vena puncture into heparinized tubes (Greiner Bio-One Company, Kremsmunster, Austria) from two average-sized pigs per pen. The blood samples were stored in 4°C refrigerator. Plasma then was separated by centrifugation and stored at -20°C until needed for analysis.

Experiment 2

Experiment 2 was conducted in the Metabolism Laboratory of the Animal Science and Technology College located on China Agricultural University. The experimental animals were obtained from the Huadu Group (Beijing, China) and comprised 42 crossbred barrows (Landrace×Large White) weighing 16.03±1.58 kg.

The pigs were housed in three rooms with temperature, humidity and ventilation rate automatically monitored through an environmental control system. The temperature ranged from 23 to 26°C while the humidity ranged from 55 to 70%, and ammonia and carbon dioxide were kept below recommended levels for the duration of experiment.

The pigs were kept individually in stainless steel metabolism crates (0.6 m×0.3 m×0.5 m) equipped with plastic slotted flooring and a 0.25 m^3 round bottom single feeder at the front. Feed in mash form was supplied three times daily at 08:00, 15:00 and 22:00 h, respectively. Between meals, the feed troughs were filled with water so that the pigs could consume as much water as they wished.

The nitrogen-balance experiment was conducted to determine the lysine bioefficacy from L-lysine sulfate and L-lysine·HCl using the same factorial design as that used in experiment 1. The swine diets are described in Table 2.

The trial consisted of a 5-day adaptation period and a 5-day collection period of urine and feces. The daily feed allowance of the experimental animal was adjusted according to feed intake of the first 4 days of acclimation period. From day 5 to 10 of the experimental period, the amount of feed provided was 790 g/d for pigs. This level of feed provided 3.2 times the pig's maintenance energy requirements (NRC, 1998). The pigs typically consumed their ration within 20 minutes.

During the 5-day collection period, the pigs were fitted with adhesive fecal collection bags that allowed separate collection of feces and urine (Van Kleef *et al.*, 1994). The

Table 3. Performance and plasma urea nitrogen (PUN) responses of growing pigs fed either L-lysine sulfate or L-lysine·HCl in experiment 1

Item	Lysine source		SEM[1]	Lysine equivalent level (%)				SEM[1]	Significance		
	L-lysine sulfate	L-lysine·HCl		0.0	0.1	0.2	0.3		Lysine source	Lysine level	Lysine source×level
Daily gain (g/d)	321	308	6.43	251	293	330	383	9.10	0.14	p<0.01	0.13
Feed intake (g/d)	587	576	9.03	528	574	582	641	12.77	0.41	p<0.01	0.05
Feed conversion	1.87	1.91	0.02	2.12	1.98	1.77	1.69	0.03	0.08	p<0.01	0.06
PUN (mg/dl)	22.6	23.3	0.46	27.2	23.3	21.4	20.0	0.65	0.31	p<0.01	0.47

[1] SEM = standard error of the means (Root MSE/Root replication). The replication number is 6.

daily fecal collection for each pig was placed in a labeled plastic bag, frozen and stored at approximately -20°C until the end of the collection period. At that time, the feces were thawed and weighed at room temperature and pooled into uniform slurries for each pig. A sub-sample of 120 to 180 g was obtained and dried in a forced-air oven at 65°C for two days. Feces were then allowed to equilibrate with atmospheric moisture for 24 h, ground to pass through a 1 mm screen, and stored in a freezer at -20°C until needed for analysis of total fecal N.

Total urinary output was collected once daily in a plastic container located under a funnel placed below the metabolism cages. Prior to collection, 50 ml of 6 N HCl was added to each collection container to limit microbial growth and reduce loss of ammonia. Urine volume was recorded daily and then filtered, and a fixed proportion (1 to 3%) of the urine from each pig was collected in screw-capped polyethylene containers and frozen at approximately -20°C prior to analysis for total nitrogen content.

Chemical analysis

Dry matter, ash, crude fiber and crude protein in the mixed diets were analyzed according to the procedures of the Association of Official Analytical Chemists (AOAC, 1990). Amino acid concentration of the ingredients and mixed diets was determined by high performance liquid chromatography (Hitachi L-8800 Amino Acid Analyzer, Tokyo, Japan). All samples were hydrolyzed for 24 h at 110°C with 6 N HCl prior to analysis for lysine and threonine. Sulfur-containing amino acids were analyzed after performic acid oxidation and then hydrolyzed with 6N HCl for 24 h. Tryptophan was determined after alkaline hydrolysis with 4 N NaOH for 22 h at 110°C.

Fecal nitrogen and urinary nitrogen were analyzed with a semi-automatic analyzer (Kjeltec™ 2100 Distillation Unit) by the Kjeldahl method. Plasma urea nitrogen was measured with Automatic Biochemical Analyzer (Technicon RA 1000).

Statistical analyses

Data for both experiments were analyzed as a factorial design with the factors in the model consisting of lysine source, lysine level and their interaction. Data were analyzed using the general linear model (GLM) procedures of SAS (2000). Pen was used as the experimental unit in experiment 1 and pig served as the experimental unit in experiment 2. A t-test was conducted to determine if there was difference between L-lysine sulfate and L-lysine·HCl. The multivariate linear regression model was used to determine the biological efficacy of lysine in L-lysine sulfate compared with lysine in L-lysine·HCl. Data were fitted in the multivariate linear regression model with the following equation:

$$y = a+b_1 \times x_1+b_2 \times x_2$$

where y = performance criterion (daily gain, feed conversion, plasma urea nitrogen, nitrogen retention), a = intercept (animal performance with the basal diet), b_1 = slope of L-lysine sulfate line, b_2 = slope of L-lysine·HCl line, x_1 = value for L-lysine sulfate, and x_2 = value for L-lysine·HCl (Littell *et al.*, 1997). The multivariate linear regression model was composed of two straight lines that shared a common intercept. The variables, daily gain, feed conversion, plasma urea nitrogen and nitrogen retention, were regressed against supplemental lysine intake. The bioefficacy was calculated using: x_1/x_2, where x_1 = L-lysine sulfate and x_2 = L-lysine·HCl. The results were considered significant if $p<0.05$.

RESULTS

There was no difference ($p>0.05$) in the performance of pigs fed L-lysine sulfate compared with L-lysine·HCl (Table 3). Plasma urea nitrogen also did not differ ($p>0.05$) between pigs fed the different lysine sources. Increasing the level of lysine in the diet significantly ($p<0.01$) improved daily gain, feed intake and feed conversion, while plasma urea nitrogen was significantly ($p<0.01$) reduced by the addition of dietary lysine. There were no significant interactions ($p>0.05$) between lysine source and lysine level for any performance parameters.

The relative bioefficacy of L-lysine sulfate to L-lysine·HCl was compared using a multivariate linear regression model. The bioefficacy of L-lysine sulfate relative to L-lysine·HCl was 1.01 for daily gain (Figure 1).

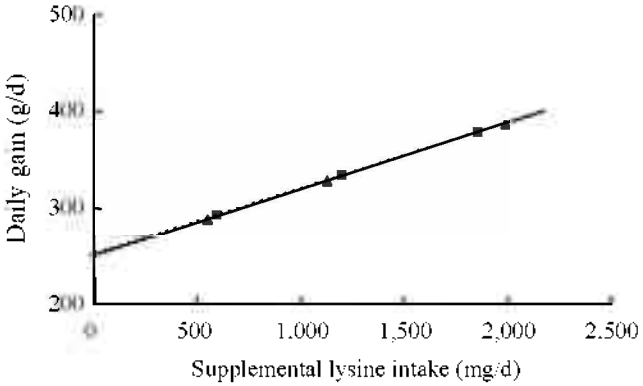

Figure 1. Daily gain was fitted in the multivariate linear regression model with the equation: $y = 252+0.0684\times x_1+0.0680\times x_2$, which matched x_1 = value for L-lysine sulfate, x_2 = value for L-lysine·HCl, and $R^2 = 0.94$. 168 pigs were used in six replicates per treatment in a 21-d growth assay. The bioefficacy of lysine in L-lysine sulfate (-■-) relative to that in L-lysine·HCl (--▲--) with the common basal diet (●) was 1.01 for daily gain ($p>0.05$).

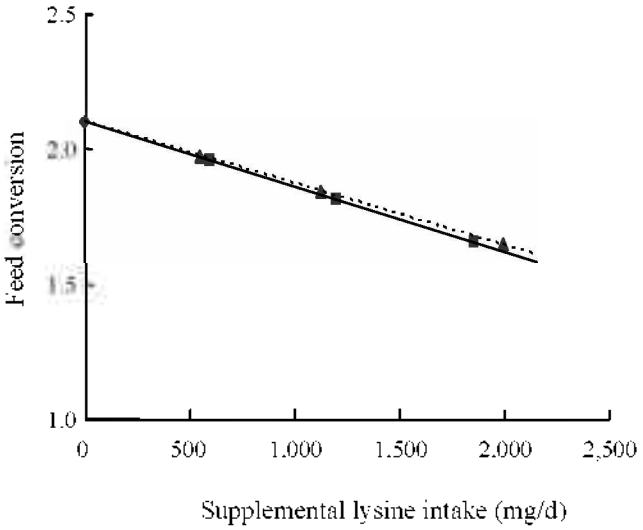

Figure 2. Feed conversion was fitted in the multivariate linear regression model with the equation: $y = 2.1-0.00024\times x_1-0.00023\times x_2$, which matched x_1 = value for L-lysine sulfate, x_2 = value for L-lysine·HCl, and $R^2 = 0.85$. 168 pigs were used in six replicates per treatment in a 21-d growth assay. The bioefficacy of lysine in L-lysine sulfate (-■-) relative to that in L-lysine·HCl (-▲-) with the common basal diet (●) was 1.05 for feed conversion ($p>0.05$).

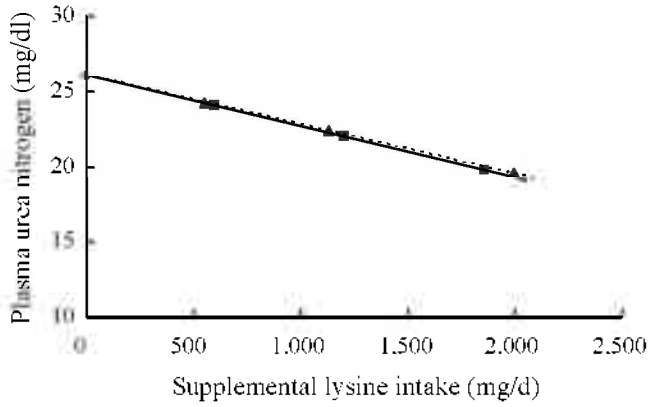

Figure 3. Plasma urea nitrogen was fitted in the multivariate linear regression model with the equation: $y = 26-0.0034\times x_1-0.0033\times x_2$, which matched x_1 = value for L-lysine sulfate, x_2 = value for L-lysine·HCl, and $R^2 = 0.91$. 168 pigs were used in six replicates per treatment in a 21-d growth assay. The bioefficacy of lysine in L-lysine sulfate (-■-) relative to that in L-lysine·HCl (-▲-) with the common basal diet (●) was 1.04 based on plasma urea nitrogen ($p>0.05$).

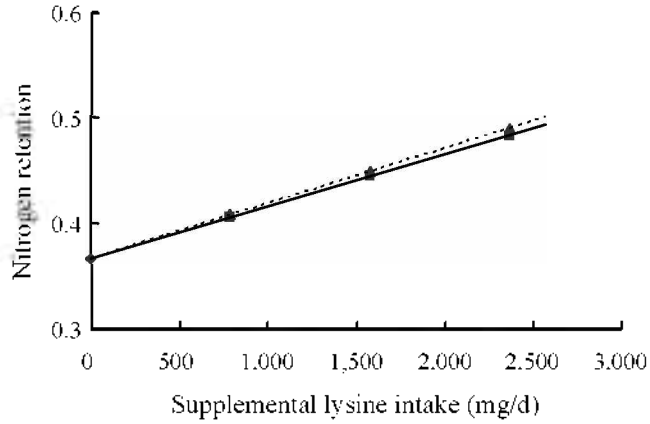

Figure 4. Nitrogen retention was fitted in the multivariate linear regression model with the equation: $y = 0.368+0.000049\times x_1+0.000051\times x_2$, which matched x_1 = value for L-lysine sulfate, x_2 = value for L-lysine·HCl, and $R^2 = 0.98$. 42 pigs were used in six replicates per treatment in a 10-d nitrogen-balance assay. The slope ratio procedure for comparison of the response from the two lysine sources with the common basal diet (●), demonstrated a relative biological equivalence value of L-lysine sulfate (-■-) to L-lysine·HCl (-▲-) of 0.95 based on nitrogen retention ($p>0.05$).

1.05 for feed conversion (Figure 2) and 1.04 based on plasma urea nitrogen (Figure 3). However, these values were not different ($p>0.05$) from 1.00 as determined by t-test analysis.

There was no difference ($p>0.05$) in nitrogen balance due to lysine source (Table 4). Urinary nitrogen declined while nitrogen retention increased significantly ($p<0.01$) due to increasing level of dietary lysine. No significant interactions ($p>0.05$) occurred between lysine source and lysine level for any nitrogen balance parameter. The slope ratio procedure for comparison of the response from the two lysine sources demonstrated a relative biological equivalence value of L-lysine sulfate to L-lysine·HCl of 0.95 based on nitrogen retention (Figure 4).

DISCUSSION

Supplementing the lysine deficient basal diets with either L-lysine sulfate or L-lysine·HCl resulted in an

Table 4. Nitrogen-balance responses of growing pigs fed either L-lysine sulfate or L-lysine·HCl in experiment 2

Item	Lysine source		SEM[6]	Lysine equivalent level (%)				SEM[6]	Significance		
	L-lysine sulfate	L-lysine·HCl		0.0	0.1	0.2	0.3		Lysine source	Lysine level	Lysine source×level
N intake[1] (g/d)	26.42	26.42	-	26.42	26.42	26.42	26.42	-	-	-	-
Fecal N[2] (g/d)	3.18	3.22	0.09	3.27	3.43	3.12	2.98	0.13	0.77	0.11	0.64
Urinary N[3] (g/d)	12.00	11.82	0.09	13.21	12.34	11.62	10.48	0.13	0.16	p<0.01	0.16
Retained N[4] (g/d)	11.24	11.38	0.12	9.94	10.65	11.69	12.96	0.17	0.41	p<0.01	0.76
N retention[5]	0.426	0.432	0.0043	0.377	0.403	0.443	0.491	0.0061	0.32	p<0.01	0.70

[1] N intake = Daily feed consumption during the collection period×feed N content.

[2] Fecal N = Total feces weight, air dry basis×feces N content/5 d.

[3] Urinary N = Total urinary volume×urinary N content/5 d.

[4] Retained N = N intake-fecal N-urinary N.

[5] N retention = Retained N/N intake.

[6] SEM = standard error of the means (Root MSE/Root replication). The replication number is 6.

expected improvement, both in pig performance and in nitrogen retention. This means that the relative effectiveness of the two sources of lysine was tested in the sensitive range (Heugten and Frederick, 2000). Huyghebaert (1993) observed that the bioefficacy of two nutrient sources should only be compared when the basal diet is clearly deficient in the nutrient to be tested. Baker (1986) suggested that the basal diet should provide approximately 30 to 70% of an animal's requirement while the basal diet used for the present experiment (0.67% lysine) supplied 58% of the lysine requirement of 10 to 20 kg pigs (NRC, 1998).

Over the 21 d growth period, there was no difference in daily gain, feed intake or feed conversion for weaner pigs fed diets supplemented with L-lysine sulfate or L-lysine·HCl. These findings are consistent with previous finding in pigs (Heugten and Frederick, 2000). Additionally, in the study of Smiricky-Tjardes *et al.* (2004) there were 100 nursery pigs with an average initial weight of 9.5 kg allotted randomly to five treatments with five replicates of four pigs per pen in the experiment and the analysis revealed that the bioefficacy of lysine in L-lysine sulfate was not significantly different from the lysine in L-lysine·HCl.

Both L-lysine sulfate and L-lysine·HCl, are produced by bacterial fermentation of carbohydrates, but the post-fermentation process for L-lysine sulfate differs from that of L-lysine·HCl. L-lysine sulfate is reported to contain other amino acids, phosphorus and energy, not present in L-lysine·HCl (Jackson, 2001). In addition, Smiricky-Tjardes *et al.* (2004) suggested that the presence of dried microbial cells in L-lysine sulfate may have positive effects on the performance of animals fed diets supplemented with this lysine source. However, neither the presence of additional nutrients or dried microbial cells appeared to have any effect on the performance of pigs fed the different lysine sources in our present study.

Plasma urea nitrogen was inversely related to the dietary amino acid balance. This finding is similar to previous experiments with amino acid imbalanced diets (Kumta and Harper, 1961; Brown and Cline, 1974). In general, a reduction in plasma urea nitrogen is indicative of a more efficient use of dietary nitrogen as it has been shown that plasma urea nitrogen concentrations are reduced continuously until a dietary amino acid balance is met by supplementing the limiting amino acid to the diet (Coma et al., 1995; Figueroa et al. 2002; Nyachoti et al., 2006).

Most researchers have used growth trials to determine the bioefficacy of L-lysine sulfate relative to L-lysine·HCl and few nitrogen-balance trials have been conducted to compare the bioefficacy of the different lysine sources. However, the nitrogen-balance technique is a good method to compare the bioefficacy of amino acids. In fact, Figueroa et al. (2002) suggested that a nitrogen-balance trial was more sensitive to amino acid adequacy than a growth trial using pigs. However, even when using nitrogen balance, there was no difference in the relative bioefficacy of lysine in L-lysine sulfate compared with L-lysine·HCl, and these results were closely in accordance with those obtained in a methionine bioefficacy experiment conducted by Zimmermann et al. (2005). The nitrogen balance finding supports that of Rodehutscord et al. (2000), who reported no differences in nitrogen balance for rainbow trout (*Oncorhynchus mykiss*) fed these two lysine sources.

The overall results of our study indicate that the relative biological efficacy of lysine in L-lysine sulfate is not significantly different from lysine supplied by L-lysine·HCl. Our results show that the relative bioefficacy values from the two lysine sources, assessed by two entirely different analytical strategies (growth and nitrogen-balance trials), do not differ. Thus, L-lysine sulfate is roughly equal to L-lysine·HCl as a source of supplemental lysine for use in diets fed to 10 to 20 kg pigs.

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